DOI/BC/15127-2

An Advanced Fracture Characterization and Well Path Navigation System for Effective Re-Development and Enhancement of Ultimate Recovery from the Complex Monterey Reservoir of South Ellwood Field, Offshore California

Quarterly Technical Progress Report

Reporting Period Start Date: **October 1, 2000**

Reporting Period End Date: **December 31, 2000**

Principal Investigators: Karen Christensen (Venoco), Iraj Ershaghi (USC)

Issue Date: **January 31, 2001**

Cooperative Agreement No. **DE-FC26-00BC15127**

Submitting organizations:

Venoco Inc
5464 Carpinteria Ave. Suite J
Carpinteria, CA 93013-1423

University of Southern California
University Park
Los Angeles, CA 90089-1147

Progress Report October 1 - December 31, 2000

Disclaimer

Abstract

Venoco Inc, intends to re-develop the Monterey Formation, a Class III basin reservoir, at South Ellwood Field, Offshore Santa Barbara, California.

Well productivity in this field varies significantly. Cumulative Monterey production for individual wells has ranged from 260 STB to 8,700,000 STB. Productivity is primarily affected by how well the well path connects with the local fracture system and the degree of aquifer support. Cumulative oil recovery to date is a small percentage of the original oil in place. To embark upon successful re-development and to optimize reservoir management, Venoco intends to investigate, map and characterize field fracture patterns and the reservoir conduit system. State of the art borehole imaging technologies including FMI, dipole sonic and cross-well seismic, interference tests and production logs will be employed to characterize fractures and micro faults. These data along with the existing database will be used for construction of a novel geologic model of the fracture network. Development of an innovative fracture network reservoir simulator is proposed to monitor and manage the aquifer's role in pressure maintenance and water production. The new fracture simulation model will be used for both planning optimal paths for new wells and improving ultimate recovery.

In the second phase of this project, the model will be used for the design of a pilot program for downhole water re-injection into the aquifer simultaneously with oil production. Downhole water separation units attached to electric submersible pumps will be used to minimize surface fluid handling thereby improving recoveries per well and field economics while maintaining aquifer support.

In cooperation with the DOE, results of the field studies as well as the new models developed and the fracture database will be shared with other operators. Numerous fields producing from the Monterey and analogous fractured reservoirs both onshore and offshore will benefit from the methodologies developed in this project.

This report presents a summary of all technical work conducted during the second quarter of Budget Period I.

Table of Contents

Introduction

The Field Demonstration site for this Class III (basin clastic) Program Proposal is the South Ellwood Field located offshore California. The Monterey Formation is the main producing unit in the South Ellwood Field and consists of fractured chert, porcelanite, dolomite, and siliceous limestone interbedded with organic mudstone. This reservoir has an average thickness of 1,000 feet, and lies at subsea depths of approximately -3,500’ to -5,000’.

Venoco and USC jointly submitted an application to conduct a DOE co-operative investigation of the Monterey formation at South Ellwood in June 2000. The DOE granted this application in July 2000.

Executive Summary

Venoco and USC prepared a proposal for a DOE sponsored joint investigation of the fractured Monterey formation. It was agreed that Venoco would construct the geologic model for the field and gather new reservoir data as appropriate. USC would then develop a simulation model that would be used to optimize future hydrocarbon recovery. Joint Venoco-USC teams were established to manage the flow of data and insure that Venoco and USC activities remained synchronized. A co-operative agreement was signed with the DOE on July 31, 2000.

The first new data was acquired during this quarter. Schlumberger ran a Water Flow log in the long string of E-11 to determine the point of water entry into the Monterey perforations in the short string. This was the first time a production log had been run to identify flow patterns in the short string. Normally this is impossible in dual completions due to the probability of losing the logging tools. We expect that this technique will be of great value to other operators using dual completions. In spite of the wildly slugging flow in the wellbore, the WFL was able to identify the source of the water entry as the lowest set of perforations in the Monterey. Venoco will be able to plug off these perforations in a future workover. The results of this unique log will be presented in a forthcoming SPE paper.

A Fetkovich type curve analysis of the South Ellwood production data was undertaken to obtain values of permeability to input into the simulation model. This analysis showed that most wells followed a pattern of rapid decline from initially high production rates to more sustainable levels. This is fairly typical for a fractured reservoir where fractures provide the initially high productivity but the storage volume in the matrix acts to insure stable production later in the well's life. The early onset of this support mechanism indicate the South Ellwood wells fit more closely to the dual fracture model rather a conventional dual porosity model. The results of this study were presented at a regional SPE meeting in Bakersfield.

A parallel study was begun to identify individual fractures from the well log data. All of the South Ellwood wells were drilled before the use of imaging tools became widely available. A pattern recognition technique was developed to distinguish highly fractured intervals from conventional logs such as caliper, resistivity, density/neutron and sonic traces.

Additional progress was made in completing the geological model to include fault indications from the dipmeter logs and compiling reservoir data for the simulation model. The updated South Ellwood geological model was presented at a meeting of the Coast Geological Society.

Task I-Database

Continued populating the database with log data, core data and other digitized versions of the hard copy data. Table I shows the current state of the database.

Task II- New Data

Ran a Schlumberger Water Flow Log in the long string of Gail E-11L to determine source of water entry into the short string Monterey perforations. Previously it had been impossible to run production logs in the short string of dual completions due to significant risk of wrapping the logging tools around the long string. The WFL log showed that 100% of the water was entering the bottom set of perforations. This allows Venoco to plan a water shut-off treatment on a future workover. The results of this unique log run will be published in an SPE paper. This technology will thus be made available to other operators with dual completions.

Task III-Geological/Reservoir Engineering

Geologic Model

The geologic model was expanded to include detailed fault interpretations from well ties and dipmeters. The careful integration of this data within the 3D geologic model allowed for much more subtle faulting and fracturing to be identified. By example, 33 faults identified by traditional log correlations expanded into over 130 fault cuts. The refinement also lead to the identification of 4 NNE trending tear zones that may prove to be major conduits for fluid flow.

Production Type Curve Analysis:

We started a detailed study examining the permeability characteristics of the South Ellwood reservoir using the performance data from individual wells. In this field, the wells that intersect highly fractured and brecciated intervals are the most prolific producers. Historical production data on individual wells were examined using a type curve approach. The early production decline, from fracture-controlled period, was used to estimate equivalent permeability-thickness product for individual wells. The matching process is similar to the method suggested by Fetkovich for homogeneous reservoirs. Deviation from this model, attributed to a support system, is compared with two plausible systems. The two systems compared are the dual-fracture model published by Al-Ghamdi and Ershaghi, which is selected for its representation of network of micro fractures as the main support system, and the dual porosity/permeability models which are the most commonly used models in commercial simulators to represent naturally fractured reservoirs. The objective of this study is to generate estimates of fracture permeability from production data. Such information will be very helpful in setting up the conventional and the proposed pipeline simulation models.

Conceptual dual porosity models representing naturally fractured reservoirs predict several logarithmic cycles of time data before support from a tight matrix can be recognized as shown in Fig. 1. For tight rocks susceptible to fracturing, Al-Ghamdi *and* Ershaghi proposed a dual fracture system where the support to major fractures is from a network of microfractures illustrated in Fig. 2. Because of high interporosity coefficients attributed to high permeability of microfractures, the onset of support system(s) occurs faster than that observed in dual porosity tight matrix systems. This support system is, however, of smaller storativity characteristics than those observed in granular matrix rocks.

The dual fracture reservoir model can be used to interpret declining production rates from a naturally fractured reservoir and to obtain representative values of interporosity flow and fracture storativity. This type curve is illustrated in Fig 3.

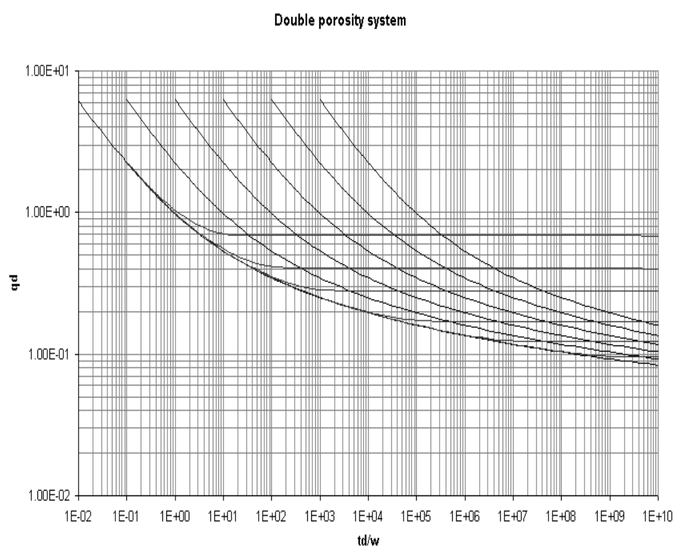


Fig. 1 Dual Porosity decline Type Curve

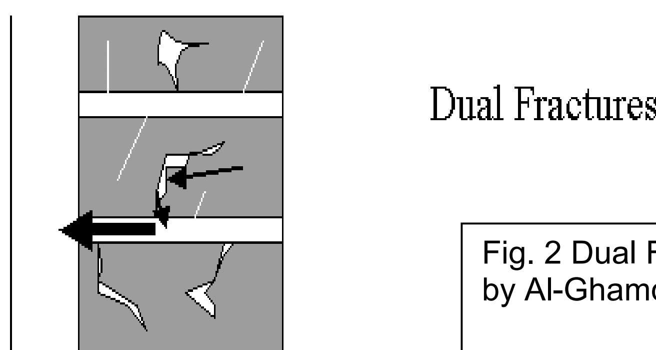


Fig. 2 Dual Fracture system introduced by Al-Ghamdi & Ershaghi for a NFR

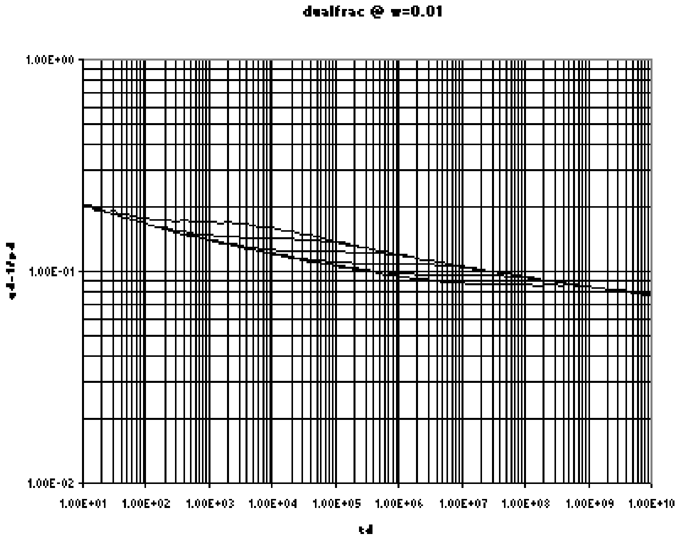


Fig.3 Dual Fracture decline Type Curve for w=0.01

Fracture Mapping

We started a new effort in integrating various signals from well logs to identify fractured and brecciated intervals. The objectives of this study is to not only help in correct building of the simulation model but to also identify untapped intervals for workover and re-completion.

Original wells drilled in the South Ellwood Field included conventional measurements such as SP, resistivity, formation density, sonic travel time, gamma ray, and caliper log. In more recent wells they also include dual induction laterolog, compensated neutron formation density, spectralog, and four-arm caliper log. Cannon noticed early on that expected well log responses were not observed in the Monterey Formation. The Monterey was known as the Monterey Shale because of the lack of character on the SP log. The more modern logs have been examined by some for finding potential intervals in the Monterey Formation. Based on the lithological description from outcrop studies, core photos, and mud logs, a host of lithological units may be observed within a typical Monterey column.

From the analysis of published studies and statistical review of data for the South Ellwood Field, we have developed a classification system as shown in Figure 4. Type A, the most prolific sections of the Monterey are the fractured and/or brecciated intervals with very high permeability often indicated by mud invasion, borehole size increase and reversal of the resistivity curves. These intervals show very poor core recoveries. This type can be easily distinguished from Type D, the shaley section, which also exhibits an increase in borehole size, higher neutron porosity vs. density porosity relation and low resistivity measurements. Type B, corresponding to the dolomitic section, exhibits mud cake buildup with indication of low to medium porosity and permeability. Type C includes all the units within the Monterey that contain rock of some finite porosity and permeability and behave similar to granular type sandstone layers. This includes sections of the Opal CT type rocks. Presence of mud cake and normal invasion, as indicated by separation of the deep and shallow resistivity tools, are initial indicators of this type of flow unit. In type E, a hard streak is exhibited with its characteristics low sonic travel time. Finally, type F signifies the presence of highly laminated cherty sections composed of various stages of silica diagenesis; this is indicated by relatively perfect hole size, high resistivities and low gamma ray.

A controlling factor, affecting the well log responses, is the amount of detrital material within each of the indicated flow units. An increase in detrital material is associated with increase in neutron porosity, gamma ray and a lowering of resistivity. To identify these intervals with production potential, (IWPP), a systematic screening process is followed. The low gamma ray intervals are identified. The caliper log is examined to determine hole size increase or mud cake buildup. Intervals with perfect hole size are excluded. The invasion pattern is then studied for mud invasion vs. only fluid invasion. Intervals are also examined to exclude those with high detrital content.

To distinguish the lithology types, the caliper observations are further cross checked. All the intervals indicating hole enlargement are then checked for shale content by examining the neutron porosity vs. density porosity relationship. All the intervals that have neutron porosity higher than density porosity are excluded. A look at the mud invasion pattern will confirm the identification of the bracciated or fractured interval from the dolomitic or Opal CT sections. The double check is to correct any interval missed by the caliper. A further investigation into the relationship between neutron porosity and density porosity in the intervals, where there is mud cake buildup, will distinguish between dolomitic sections and Opal CT. The Opal CT will read a higher porosity.
After applying many statistical methods to the data, we developed a pattern recognition technique using a radar diagram approach. The seven log signals; gamma ray, density porosity, neutron porosity, sonic travel time, deep and shallow resistivity, and caliper, were placed on the radar diagram with the high signal reading on the outside and thus the low in the center. Each signal was normalized to a characteristically high reading for the Monterey formation. The radar diagram has an axis that reads from 0 to 1 - see Fig 5. The six lithological units have very distinct characteristics.

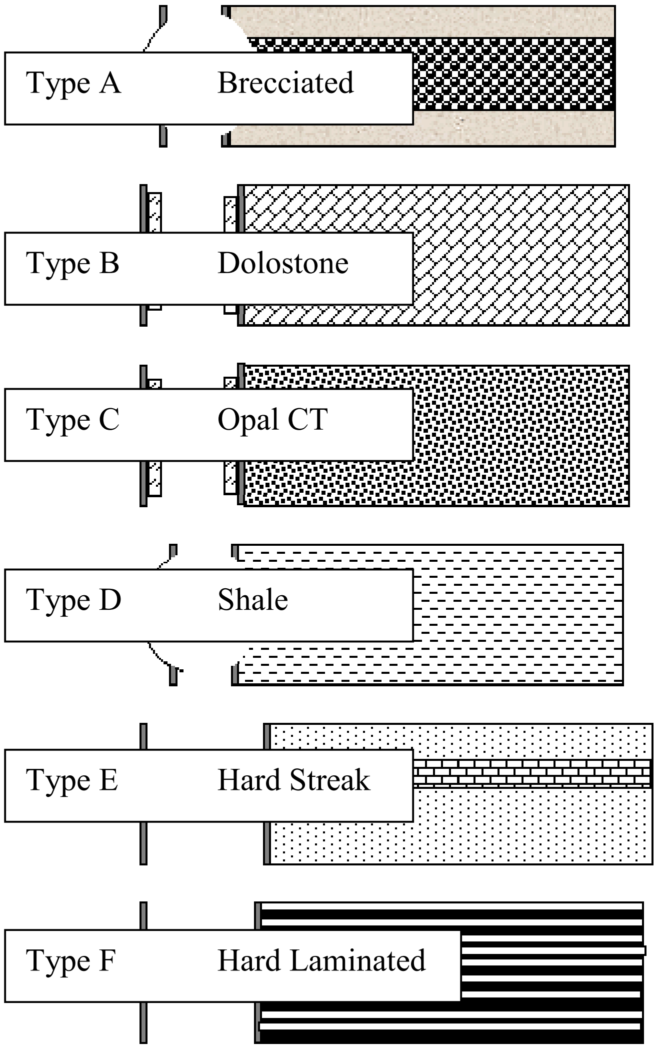
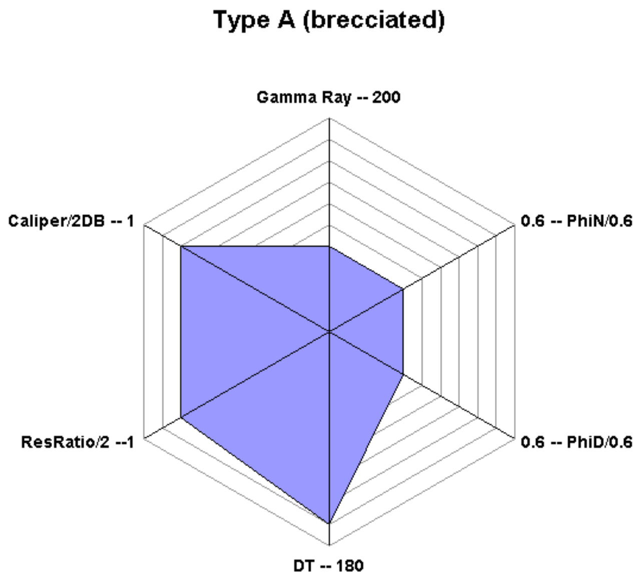


Figure 4 – Expected lithological units.

Fig.5 shows the radar diagram for a typical productive brecciated interval.



Basic reservoir engineering

Material Balance Studies

An interactive spreadsheet (through the combination of Fetkovich procedure, material balance technique, and voidage calculation procedure) was developed to calculate the original oil in place, yearly voidage, and aquifer water influx constant.

Basic material balance equation expressed as a straight line was used as a graphical criteria to determine the amount of original oil in place. The extent of departure of the line representing MBE from linearity can be easily related to the strength of aquifer support.

Voidage Calculation:

Yearly production of oil, gas and water were converted back to reservoir conditions at respective pressures.

Water influx constant:

The yearly voidage (at reservoir condition) was set proportional to available pressure difference influx potential, with the proportionality constant being equal to water influx constant (K).

Preparation for Reservoir Modeling

CMG's IMEX simulator will be used for this reservoir simulation study. In general, a comprehensive application of structural information, well log data, traditional reservoir engineering study and numerical reservoir simulation study is required to understand the reservoir and optimize future reservoir management. The production data reflects the actual production performance history of the reservoir. This information will provide dependable reservoir description data. By conducting detailed material balance and decline curve analyses, this study will provide important reservoir information such as OOIP, porosity, water saturation and so on.

In preparation for modeling a base case using a reservoir simulator, well production performances and other reservoir data were reviewed. Production performance and reservoir pressure data indicate that there may be more bottom and edge water influx than was thought originally.

With assistance from the geology group, subsurface geophysical data including sonic, SP and resistivity logs and depositional environmental information will be used to obtain an image of the reservoir parameters such as permeability, porosity, water saturation, WOC, etc. The fluid properties such as oil viscosity can be determined based on the oil gravity and gas-oil ratio using a established correlations.

The data obtained from well log analysis, material balance analysis, PVT fluid analysis and traditional reservoir engineering studies will be used to build a numerical reservoir model. After developing the initial model, it will be history matched to the actual performance to fine-tune the reservoir parameters such as porosity, permeability, saturation distribution, water-oil contacts and size of the aquifer. After appropriate history matching, a meaningful prediction and optimization of future operation including well placement can be done. Additionally this model work will be used to calibrate the more straight forward pipeline model for its eventual routine application.

The following is the list of sub-tasks for completion of the simulation model.

Geological model definition- In progress
Grid structure definition-In progress
Pre-processing-in Progress
History match
Post-processing
Prediction based on history-matched reservoir model.
Reservoir management optimization and new well placement

Task IV-Stimulation

None

Task V-Project Management

Project review meetings were held on a monthly basis at the Venoco offices in Santa Barbara. Progress reports on various components of the project were presented by research personnel from both organizations.

The following individuals contributed to the research activities during this quarter:

Database:
Ursula Wiley (USC), Kim Halbert (Venoco) Tim Rathman (Venoco), Chris Knight (Venoco) and I. Ershaghi (USC)

Reservoir Studies:
I. Ershaghi (USC), Lang Zhang (USC), A. Zahedi (USC), Juan Angiano (USC), Ursula Wiley (USC)

Geological Modeling
Mike Wracher (Venoco), Karen Christensen (Venoco)

Geophysical Modeling
Karen Christensen (Venoco)

Project Management:
Karen Christensen (Venoco) and I. Ershaghi (USC)

Task VI-Tech Transfer

We worked with Dr. Ernie Majors at Lawrence Livermore Labs, Dr. David Weinberg at Idaho National Laboratory to propose a joint project to further investigate downhole seismic acquisition and cross well tomography.

9/19/2000 Presentation to Coast Geological Society: South Ellwood Field, Santa Barbara Channel: New Insight into Structures, Fractures, and Seeps. Karen Christensen.

Conclusions

The most significant result during the quarter was a successful test of a new logging technique to obtain production log data on short string completions. The results of this log will be presented in an SPE paper and made available to other operators with dual completions.

References:

Fetkovich, M.J.:”Decline Curve Analysis Using Type Curves,” JPT (June 1980) 1065-77.
Al-Ghamdi and Ershaghi:”Pressure Transient Analysis of Dually Fractured Reservoirs,” SPE 26959.

Kästner, M., J. B. Keene, and J. M. Gieskes, 1977, Diagenesis of siliceous oozes, I: chemical controls on the rate of opal-A to opal-CT transformation--an experimental study: Geochimica, Cosmochimica Acta, v. 41, p. 1041-1059.

Murata, K. J., and R. R. Larsen, 1975, Diagenesis of Monterey siliceous Shales, Temblor Range, California: United States Geological Survey Journal of Research, v. 3, p. 553-566

MacKinnon, T. C.: “Petroleum Geology of the Monterey Formation in the Santa Maria and Santa Barbara Coastal and Offshore Areas,”

Cannon, D. E.: “Log Evaluation of a Fractured Reservoir Monterey Shale,” SPWLA Twentieth Annual Logging Symposium, June 3-6, 1979, Q